TITLE OF INVENTION

Medium Voltage Motor Control Center Arc Resistant Enclosure

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

Field of Invention

[0003] This invention pertains to an enclosure for a medium voltage motor controller. More particularly, this invention pertains to an enclosure that is arc resistant.

BRIEF SUMMARY OF THE INVENTION

[0004] A medium voltage controller for electrical equipment, such as motors, transformers, reactors, and capacitors, is provided. The controller is a one-high unit, that is, a single contactor in a full-height cabinet, with the contactor mounted near the base of the controller, the fuses and grounding switch located near the vertical center, the disconnect switch mounted above the fuses, and the controller's instrument compartment located in the upper portion of the controller. The motor controller uses cast components to minimize components, fabrication steps, maintenance, and heat rise.

[0005] The motor controller is enclosed in an arc resistant cabinet, which uses the pressure generated by a fault to provide the sealing action to contain the fault forces. The rear, removable panels are inside the cabinet and engage lips surrounding the cabinet opening. Pressure inside the cabinet forces the panels against the inside surface of the cabinet and distributes the resulting load over a large area. The front access doors each have a continuous hinge and multiple latching tabs. The sheet metal panels of the cabinet are secured

with a dimple-in-a-dimple feature, which provides strength and rigidity to the cabinet. At points where the panels are secured, each sheet metal part is formed with a dimple having a fastener hole in its center. The corresponding dimples in each sheet metal part are mated and fastened.

[0006] Another feature of the motor controller is the swaged connections, which are used for making internal electrical connections. A swaged connection includes a terminal or connector having a barrel, into which cable conductor is inserted. The portion of the barrel enclosing the cable conductor is compressed such that the cable conductor is cold-welded to the barrel.

[0007] The pull-out contactor has a withdrawable finger cluster formed of a one piece, self-aligning formed part that electrically mates with stabs inside the cabinet. The fingers are formed from conductive material that does not require additional springs to ensure proper electrical contact.

[0008] The controller's instrument compartment is mounted in the upper portion of the controller. To aid in fabrication and maintenance, the instrument compartment includes a removable panel, which is modular and on which the instruments are wired and mounted. The instrument panel swings out of the controller to provide access to the main bus and line-side surge arrestors.

[0009] The contactor assembly is mounted on a truck and moves on a rail system that includes a pull-down handle with rails. The truck rolls out of the cabinet on the extended rails for easy removal from the cabinet. The truck, and contactor assembly, is racked in by pushing the truck into the cabinet and then raising the handle, which forces the draw-out fingers to engage the contact stabs.

[0010] A load discharge device (LDA) is included for grounding the load before the contactor can be removed from the controller. The LDA has a scissors-type closing mechanism, which, when actuated after being charged, causes a bar to contact each of the load conductors.

[0011] The fuses are mounted independently from the contactor assembly. The fuse spring clips are attached to a cast housing that provides

corona protection and, in the case of the upper fuse clip housing, serves as the lower contact for the disconnect switch.

[0012] Each phase of the disconnect switch is formed of four conducting cast components. The cast upper switch contact includes a flat contact surface to which the main bus is connected. The cast lower switch contact includes the upper fuse clip housing. The cast configuration eliminates multiple connections, which are susceptible to high resistance and, consequently, heating. Electrical continuity between each of the two switch contacts is provided by two parallel plates that contact the two switch contacts by the disconnect switch operating mechanism. In the open position, the disconnect switch is earthed.

[0013] The disconnect switch has a window through which the equipment operator can view the position of the disconnect switch when the switch illuminator is actuated. An LED is positioned to shine light into the disconnect switch to illuminate the switch components. The LED is actuated by a manual switch and is powered by a portable power supply.

[0014] Low power current transformers are positioned near the load side of the contactor. The low power current transformer is a wide-range current transformer that provides amperage information to the protective metering devices from 0 amperes to 800 amperes, or more.

[0015] Internal temperature monitoring is performed by an optical temperature measuring system. Crystals are mounted on components that could experience elevated temperatures, such as the bus connections and the draw-out stabs. A pair of non-conductive fiber optic cables are connected between each crystal and a temperature sensor. The temperature sensor transmits an optical signal through a fiber optic cable and into the crystal. The signal excites the crystal and the temperature sensor receives the resulting fluorescence signal and determines the temperature of the crystal.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0016] The above-mentioned features of the invention will become more clearly understood from the following detailed description of the invention read together with the drawings in which:

Figure 1 is a perspective view of a group of five controllers;

Figure 2 is a schematic diagram of a controller;

Figure 3 is a perspective view of a motor controller with one side panel removed;

Figure 4A is a perspective view of a cut-away of a rear panel;

Figure 4B is a cut-away top view of the rear panel;

Figure 5 is a perspective view of an exhaust vent on the top panel of the cabinet;

Figure 6 is a partial view of two mounting dimples;

Figure 7 is a side section view of a dimple-in-a-dimple assembly;

Figure 8A is a partial perspective view of a front door and latching plate;

Figure 8B is a partial plan view of a door latch;

Figure 8C is a partial plan view of a door hinge;

Figure 9 is a perspective view of a terminal and a cable;

Figure 10 is a perspective view of a terminal swaged to a cable;

Figure 11 is a perspective view of a contact finger and a terminal stab;

Figure 12 is a side view of a contact finger and stab;

Figure 13A is a right side perspective view of the instrument compartment with the door open and the instrument panel extended and swung out;

Figure 13B is a top plan view of the instrument compartment as illustrated in Figure 13A;

Figure 14 is a left side perspective view of the instrument compartment with the door open and the instrument panel extended;

Figure 15 is a perspective view of the contactor truck resting partially pulled out from its fully inserted position;

Figure 16 is a side view of the contactor truck in the position as illustrated in Figure 15;

Figure 17 is a plan view of the contactor truck in the fully inserted position;

Figure 18A is a perspective view of a load discharge device;

Figure 18B is a plan view of a portion of the load discharge device, showing the device in the charged position;

Figure 18C is a plan view of a portion of the load discharge device, showing the device in the earthed position;

Figure 18D is a plan view of the load discharge device scissors-type linkage;

Figure 18E illustrates a terminal lug for the load discharge device;

Figure 19 illustrates the disconnect switch and the fuses;

Figure 20A illustrates a two-fuse holder;

Figure 20B illustrates a three-fuse holder assembly;

Figure 21 illustrates the housing of the disconnect switch and a switch illuminator;

Figure 22 illustrates the internals of the disconnect switch in the open position;

Figure 23 illustrates a cross-section view of the internals of the disconnect switch;

Figure 24 illustrates a switch illuminator for illuminating the internals of the disconnect switch;

Figure 25 illustrates a simple schematic diagram for the switch illuminator;

Figure 26 illustrates a schematic of a low power current transformer;

Figure 27 illustrates a block diagram of an internal temperature monitoring system; and

Figure 28 illustrates the waveforms for the source and reflected optical signals.

DETAILED DESCRIPTION OF THE INVENTION

[0017] An apparatus for controlling medium voltage electrical equipment, such as motors, transformers, reactors, and capacitors, is disclosed. The apparatus, illustrated in Figure 1 in a five-wide configuration, is a medium voltage motor controller **102**, **104**, **106**, **108**, and **110**.

[0018] Figure 2 is a schematic diagram of the controller **102**. A three-phase bus **202** connects to a disconnect switch **204**, which is connected to a set of fuses **206A**, **206B**, and **206C**. Although the schematic shows one fuse **206** per phase, those skilled in the art will recognize that the physical configuration can include multiple fuses per phase in order to satisfy current carrying and current interrupting requirements. The contactor **210** is connected to the fuses **206** and load **220** through draw-out stabs and connectors **208** and **212**. Between the stabs and connectors **212** and the driven motor **M** or load **220** are a load discharge device **214** and current transformers **216** and **218**. The illustrated embodiment controls a motor **M** load. Those skilled in the art will recognize that the controller **102** can also be used to control transformers, reactors, capacitors, or other electrical equipment or loads without departing from the spirit and scope of the present invention.

[0019] Figure 3 illustrates the arc resistant cabinet **302** and the features that permit the cabinet **302** to withstand high-current faults without losing its integrity or damaging nearby equipment or personnel. Arc faults occur when a component, having a potential greater than ground potential, conducts current to ground. An arc fault releases a large amount of energy in a very short period of time. In an enclosure containing a medium or high voltage circuit breaker, when a high current fault occurs an arc is developed that creates hot ionized arc gasses and/or superheated air which cause pressure to build up within the enclosure within a short period [5 to 8 milli-seconds]. This pressure burst [5 to greater than 50 psig] can be so great that the hot arc gasses escape from the enclosure. In fact, the pressure may become so extreme as to cause the doors and side walls of the enclosure to be blown off. Electrical equipment can be designed to withstand arc faults of a specific energy. Typical arc fault ratings for equipment include 25kA for 1 second duration, 40kA for 0.5 seconds, and 50 kA for 0.25 seconds. With the addition of re-enforced end walls, the ratings can be increased to 50kA 1.0 second.

[0020] The controller cabinet **302** includes a contactor and fuse door **304**, a disconnect switch cover **306**, and an instrument compartment door **308**. The cabinet **302** further includes a floor panel **352**, which is secured to the cabinet **302** and prevents the cabinet **302** from being pushed away from the floor by the arc fault pressure impulse. The instrument compartment **1310** is isolated from the remainder of the inside of the cabinet **302** by two baffles or barriers: a vertical riser **344** and a compartment floor **342**. The vertical riser **344** has a removable panel **326** for access to any equipment located behind the riser **344**. The compartment floor **342** has a removable panel **328** for access to the bus connections at the disconnect switch. The vertical riser **344** and the compartment floor **342** prevent the arc fault pressure impulse from penetrating the instrument compartment. The disconnect switch **1902** (see Figure 19) is attached to a mounting plate **332**, which is secured to a vertical riser **334**. The mounting plate **332** and the vertical riser **334** provide support, but they do not restrict the air flow during an arc fault. Those skilled in the art will recognize that the air flow can be accomplished through orifices or air gaps in the mounting plate **332** and the vertical riser **334**.

[0021] The contactor and fuse door **304** is secured to the panel by a hinge along one side and by a series of latching tabs along the opposite side that mate with corresponding slots attached to the cabinet **302**. (See Figures 8A and 8B). The removable panels **322** and **324** are shown in the rear of the cabinet **302**. The panels **322** and **324** are installed inside the cabinet **302** and an arc fault pressure impulse seats the panels **322** and **324** against their mating surfaces. The panels **322** and **324** do not rely upon fasteners to provide structural integrity during an arc fault. (See Figures 4A and 4B). The top panel **354** of the cabinet **302** includes the arc exhaust vent **314**, which is illustrated with the two hinged flaps **314** and **316** in the closed position. (See Figure 5). The superheated air generated by an arc fault forces the hinged flaps **314** and **316** to open and exhaust, thereby reducing the maximum pressure generated within the cabinet **302**. The various surfaces of the cabinet **302** are joined with dimple-in-a-dimple connections **710** (see Figure 7), which provide joints with a high shear strength.

[0022] Figure 4A illustrates a cut-away view of the lower access panel **324** of the cabinet **302**. Also shown is the side panel **414**, which is not illustrated in Figure 3. The removable access panel **324** is mounted inside the cabinet **302**, and the panel **324** is removed by tilting it inside the cabinet **302** and drawing it out of the opening in the cabinet **302**. The removable panel **324** is attached to the cabinet **302** by fasteners inserted through openings **422** and **424** and corresponding openings in the bottom portion of the removable panel **324**. In one embodiment, the removable panel **324** has captive nuts to receive the fasteners, thereby allowing the fasteners to secure the panel **324** to the cabinet **302**. The top portion of the removable panel **324** is secured in a similar manner. Located on the outside central portion of the panel **324** is a handle **412**, which aids in removing or installing the panel **324**.

[0023] Figure 4B illustrates a section view of the rear panel, or access panel, **324** and the rear of the cabinet **302**. The access panel **324** has a flat surface with first and second panel edges **424A** and **424B** bent to form lips, or protruding members, **424**, and the opening in the cabinet **302** has a turned down edge, or wall edge, **402** with an elastic sealing strip, or resilient seal, **404** placed over or on the end of the sheet metal of either the cabinet **302** or the panel **324**. The turned down edge **402** of the cabinet **302** and the sealing strip

404 mate with the removable panel **324** and fit inside the area of the panel **324** defined by the lip **424** of the removable panel **324**. Although Figures 4A and 4B illustrate lips **424A** and **424B** on opposing sides of the panel **324**. In one embodiment, the access panel **324** has lips, or protruding members, **424** on all four sides. Figures 4A and 4B illustrate the sealing strips **404A** and **404B** that mate with the turned down edges **402A** and **402B**. The bottom and top portions **416** of the opening also use a sealing strip, which has a flat shape, that fits between the bottom portion **416** and the removable panel **324**. Although the illustrated lip **424** is at a right angle to the flat surface of the panel **324**, those skilled in the art will recognize that the lip **424** can be formed with an angle sufficient to catch the edge **402** of the cabinet **302** and prevent the panel **324** from being blown through the opening in the cabinet **302** during an arc fault.

[0024] During an arc fault, the pressure increase in the cabinet **302** pushes the removable panel **324** against the sealing strip **404**, and the force applied to the panel **324** is carried by the edges **402** of the opening of the cabinet **302**, not by any fasteners. The configuration of the removable panel **324** is such that a large panel **324** and opening, providing easy access to the controller **102** components, can be used with an arc resistant cabinet **302**.

[0025]Figure 5 illustrates the exhaust vent **312** located on the top panel **354** of the cabinet **302**. The vent **312** includes a grate **502** secured to an opening in the top panel **354**. The grate **502** has openings that permit air flow with little restriction, but prevent objects from falling into the cabinet **302**. The exhaust vent **312** also includes two flaps **314** and **316**, each of which is secured at one edge by a hinge **504**. The flaps **314** and **316** are held flat against the grate **502** by gravity. During an arc fault, the flaps **314** and **316** are forced open by the pressure impulse of heated air from inside the cabinet **302**. The superheated air and any flames are exhausted vertically from the cabinet. In another embodiment, the flaps **314** and **316** are not used, but a duct is attached to the cabinet **302** and directs the heated air away from the cabinet **302** and any objects above the cabinet **302**.

[0026] Figure 6 illustrates a pair of dimples **602** and **604** formed in a sheet metal member **342**. Each dimple **602** and **604** has a center aligned hole

612 and **614**. Figure 7 illustrates an exploded cross-section view of the dimple **604** and a panel **712** having a mating dimple **714**. A bolt **702** and nut **704** are shown; however, those skilled in the art will recognize that a rivet, sheet metal screw, or other similar fastener can be used to secure the dimples **604** and **714**, and, additionally, washers and/or lock washers can be used to secure the fastener **702** and **704**.

[0027] The dimple-in-a-dimple connection **710** results in a connection with greater shear strength than two flat sheets joined with a fastener, in which the shear strength of the joint is equal to that of the fastener. The area of the panels **342** and **712** in contact when the dimples **604** and **714** mate is the load bearing surface of the joint and provides the shear strength of the dimple-in-a-dimple connection **710**. In the illustrated embodiment, the outside dimple **604** and the inside dimple **714** have the same size and configuration, and the mating surface is less than the total concave surface area of the outside dimple **604**. In another embodiment, the dimples **604** and **714** have a size and configuration such that the inside dimple **714** is smaller than the outside dimple **604** and the surface area defined by the mating surfaces is maximized. In this embodiment, the dimple-in-a-dimple connection **710** has a greater shear strength than when the dimples **604** and **714** have the same size and configuration.

[0028] Figure 8A illustrates the front contactor door **304** with its latching mechanism **802** and mating strike assembly **804**, which is attached to the cabinet **302**. The disconnect switch cover **306** has a similar configuration. The contactor door **304** must remain closed during fault conditions. A hinge **806** secures one side of the door **304**. The opposite side of the door **304** is secured by a series of latch hooks **812** on the latching mechanism **802** that engage a series of slotted openings **814** in the strike assembly **804**. The latching mechanism **802** is moved by an operator **305** (illustrated in Figure 3), which moves the latching mechanism **802** upwards vertically to permit opening and closing of the door **304**. The operator **305** moves the latching mechanism **802** down to lock the hooks **812** in the corresponding opening **814** in the strike assembly **804**. Those skilled in the art will recognize that the latch hooks **812** can be fixed to the cabinet **302** and the strike assembly **804** can be mounted to the door **304** and operated by the operator **305**.

[0029] Figure 8B illustrates a latch hook **822**, which is one of the latch hooks **812** illustrated in Figure 8A, having a tang **824** and a slotted opening **826**. The vertical height of the latch **822**, from the end of the tang **824** to the top portion of the hood **822**, is less than the vertical height of the corresponding opening **814** in the strike assembly **804**. The lesser height of the latch **822** allows for free insertion into the corresponding opening **814**. Once inserted into the corresponding opening **814**, the latch **822** is shifted vertically such that the strike assembly **804** is positioned in the slotted opening **826** of the latch **822**. During an arc fault, any pressure on the door **304** will force the surface of the slotted opening **826** adjacent to the tang **824** against the strike assembly **804**, thereby preventing the door **304** from being forced open.

[0030] Figure 8C illustrates the door hinge **806** and the sealing lip, or channel, **834** over the hinge **806**. The hinge **806** side of the door panel **304** has a channel **834** that contains a resilient seal **842** between the channel **834** and a protruding cabinet edge **832**. The cabinet **302** has an edge, or first member, **832** that is parallel to and connected to, via a second member, a side wall and formed to fit into the door channel **834** and contact the seal **842** when the door **304** is closed. In the closed position, an arc fault forces the door **304** outwards, and the door channel **834** and seal **842** are forced into the protruding cabinet edge **832**, thereby sealing the door **304** and preventing the door **304** from being forced away from the cabinet **302**. The configuration of the door channel **834** and the cabinet edge **832** is such that as the door **304** is opened and pivots about the hinge **806**, the door channel **834** swings away from the cabinet edge **832** without restriction. This channel **834** and edge **832** configuration is similar to that used to seal the rear panels **324** and **322** to the cabinet **302**.

[0031] The illustrated embodiment shows a full length, piano-type hinge **806**. The hinge **806** does not carry any of the loads associated with an arc fault. Those skilled in the art will recognize that the hinge **806** can be other than a full length hinge and can be a style other than a piano-type hinge without departing from the scope and spirit of the present invention.

[0032] Figure 9 illustrates a connector **902** and a cable **912** before the conductor **914** is inserted into the connector opening **904**. Figure 10 illustrates the connector **902** with the conductor (conductor end and conductor body) **914**

inserted into the connector opening **904** and with the barrel **1004** of the connector **902** swaged, or compressed, at one end **1002** of the barrel **1004**. The illustrated connector **902** has a termination portion **906** that is a stab **906**, used to make a connection to a finger cluster **1104** (see Figure 11) on the pull-out contactor. Those skilled in the art will recognize that any of the various connectors or terminals in the motor controller **102** can be swaged without departing from the spirit and scope of the present invention. Illustrated in Figures 9 and 10 is a ring groove **908**. The connector **902** is fixed or mounted when the stab, or conductive member, **906** is inserted in a hole with the shoulder of the barrel **1004** against one side of the surface and a ring clip against the other side of the surface and the ring clip inserted in the ring groove **908**. The conductor **914** is copper, aluminum, or other electrically conductive material.

[0033] A swaged, or cold-welded compression, connection **1010** includes a connector **902** having a barrel **1004**, into which a conductor **914** is inserted and the barrel end **1002** enclosing the conductor **914** is compressed such that the conductor **914** is cold-welded to the barrel **1004**. The end of the cable **912** is cut and a portion of the insulation **916** is removed in a manner similar as with a typical crimp joint connection. After the conductor **914** is inserted into and seated in the barrel **1004**, the barrel end **1002** is placed in the jaw of a swaging tool (not illustrated) that compresses the barrel end **1002** and compression welds the barrel end **1002** to the conductor **914**. The barrel end **1002** is compressed circumferentially such that, under the compression pressure, the metals of the barrel end **1002** and the conductor **914** cold-flow and fuse to form an electrical and mechanical joint. Unlike the joint formed by crimping, the joint formed by cold-welding extends uniformly around the circumference of the conductor **914**. The swaged connection **1010** is wrapped with tape or otherwise sealed in the area between the barrel end **1002** and the cable insulation **916**. By swaging the cable **912** and the connectors **902** in the controller **102**, the incidence of loose connections and associated temperature rise is reduced, if not eliminated.

[0034] In the controller **102**, swaged connections **1010** are used on the ends of the interconnecting cables connecting the various internal components of the controller **102**. The internal components include, but are not limited to,

the contactor stabs **902**, the potential transformers, the load-side earthing device lugs **1802**, and the line-side surge arrestors. The illustrated embodiment shows a stab connector **902**; however, the swaged connections **1010** include, among others, "tee" connectors, lug connectors **1802**, and hooked lug connectors.

[0035] Figure 11 illustrates a connector **902** and a mating finger cluster **1104**. Figure 12 illustrates a side view of the finger cluster **1104**. The one-piece finger cluster **1104** has an opening in the base **1202** through which the finger cluster **1104** can be electrically and mechanically connected to the draw-out contactor assembly. The means of attaching the base **1202** to the draw-out contactor assembly are known in the art. A source of failure for many prior art controllers has been the current carrying interfaces (fingers or disconnecting means) between the contactor and the stab. The prior art fingers or disconnecting means include separate parts held together by other components and springs. These components jam and oftentimes break, causing the circuit connection to be less than as designed. Figure 2 shows the schematic representation of the draw-out stabs and connectors **208** and **212**.

[0036] The illustrated one-piece finger cluster **1104** of the present invention does not require springs. The finger cluster **1104** is copper or other conductive material and is made in the shape of a water vase with slots along its side. The slots separate the individual fingers **1112**. Each of the fingers **1112A** through **1112H** are resilient and apply a spring force when displaced radially away from the longitudinal axis of the finger cluster **1104**. When the connector stab **1102** is inserted in the throat **1204** of the finger cluster **1104**, the fingers **1112** spring apart, allowing for easy insertion of the connector stab **1102**. After insertion of the stab **1102**, the opposing pairs of fingers **1112A** - **1112E**, **1112B** - **1112F**, **1112C** - **1112G**, and **1112A** -**1112G** are spring clamps that press against the connector stab **1102** and provide parallel current paths.

[0037] In one embodiment, the finger cluster **1104** is cut from a flat sheet of copper or other conductive material. The fingers **1112** are bent perpendicular to the base **1202** and the distal ends of the fingers **1112** define a constricted throat **1204** with a diameter less than the connector stab **1102**

diameter when the cluster **1104** is not engaging the stab **1102**. The cylindrical shape aids in the control of electrical fields around the finger cluster **1104**, thus improving the dielectrics of the system.

[0038] Figure 13A illustrates a perspective view of the instrument compartment **1310** of the controller **102**. Figure 13B is a top view of the instrument compartment **1310** and cabinet **302** in the position illustrated in Figure 13A. The instrument compartment **1310** is defined by two barrier panels: the vertical riser **344** and the compartment floor **342**. An isolation assembly including the barrier panels **344** and **342** separates the cabinet **302** into two compartments: the instrument compartment **1310** and a high-voltage compartment. (See Figure 3).

[0039] In Figures 13A and 13B, the instrument compartment door **308** is open and pulled away from the cabinet **302**, and the instrument mounting panel **1302** is partially extended and partially swung away from the slide plate **1304**. The instrument mounting panel **1302** is in the disconnect position when the panel **1302** is in the illustrated position. The instrument mounting panel **1302** is a modular removable panel on which the instruments are wired and mounted. The instrument compartment **1310** is isolated from the line and load-side components in the cabinet **302**, and serves to prevent inadvertent contact with high-voltage components by the operator.

[0040] Visible in Figure 13B are the outer slide mechanism **1402** and the inner slide mechanism **1404**, which together form a telescoping assembly. The inner slide mechanism **1404** is a telescoping member attached to the slide plate **1304**. Those skilled in the art will recognize that any of various sliding mechanism configurations can be used without departing from the scope and spirit of the present invention. The instrument mounting panel **1302** is attached to the slide plate **1304** by a panel hinge or other pivoting mechanism **1306**. Those skilled in the art will recognize that the telescoping assembly **1402** and **1404** can be attached directly to the instrument mounting panel **1302** without using the slide plate **1304** without departing from the scope and spirit of the present invention.

[0041] Figure 14 illustrates a perspective view of the instrument compartment **1310** as seen from the left side of the cabinet **302**. Shown in this

figure are the slide mechanisms **1402** and **1404** that allow the instrument compartment **1310** to be slid out of the cabinet **302**. The instrument mounting panel **1302** is shown extending out of the cabinet **302**, but it is still flush to the slide plate **1304**. In the illustrated position, the instrument mounting panel **1302** is in the test position, and the relaying and wiring mounted on the instrument mounting panel **1302** can be checked and the controller **102** is fully operational.

[0042] The instrument compartment **1310** has three primary configurations. First, with the instrument compartment door **308** closed, as illustrated in Figure 3, the controller **102** is in a fully operational configuration and the components mounted in the instrument compartment **1310** are protected. Second, with the instrument compartment door **308** open and the instrument mounting panel **1302** extending out of the cabinet **302**, the instrument compartment **1310** is in a test configuration with the controller **102** fully operational and the components mounted in the instrument compartment **1310** exposed for testing and checking. Third, with the instrument compartment door **308** open and the instrument mounting panel **1302** extending out of the cabinet **302** and swung out away from the cabinet **302**, the instrument compartment **1310** is in a disconnect configuration with the controller **102** not operational and the rear panel **326** and the bottom panel **328** (both illustrated in Figure 3) accessible. In the disconnect configuration, the controller **102** is interlocked with the instrument mounting panel **1302** position and the controller **102** is in the off position, that is, the disconnect switch **1902** is open and the contactor is open. The interlock can be a mechanical linkage and/or an electrical circuit that prevents closing the contactor and/or closing the disconnect switch **1902**. The rear panel, or riser, **344** has a removable panel **326** for access to components mounted in the interior of the cabinet **302**, such as the line-side surge arrestors. The bottom, or floor, panel **342** has a removable panel **328** for access to the bus connections **2302** to the disconnect switch **1902** (illustrated in Figure 21).

[0043] Figures 15 and 16 illustrate the contactor truck **1512** in a partially removed position. The contactor truck **1512** supports the contactor assembly (not illustrated), and the truck **1512** aligns the contactor assembly when it is racked into the controller **102**. The racking assembly **1504** is

illustrated in the lowered position, where it serves as a rail for the wheels **1514** and **1516** of the truck **1512**, allowing the truck **1512** to roll out of the cabinet **302** for removal from the controller **102**. A stationary rail **1522** is aligned with the racking assembly **1504** and supports the wheels **1514** and **1516** when the truck **1512** is inside the cabinet **302**.

[0044]Figure 17 illustrates the racked truck **1512** with the racking assembly **1504** in the racked position. To rack the truck **1512**, the truck **1512** is rolled into the cabinet **302** until resistance prevents it from being rolled further into the cabinet **302**. The racking handle **1506** is raised, causing the racking assembly **1504** to rotate about a pivot point **1602**. As the racking assembly **1504** rotates, the rail portion contacts the front portion of the wheels **1514** and forces the truck **1512** into the fully racked position. In one embodiment, an upper rail is positioned slightly above the wheels **1514** and **1516** and serves to prevent the wheels **1514** from being pushed off the lower stationary rail **1522** by the racking assembly **1504**. To unrack, or remove, the truck **1512**, the racking handle **1506** is pulled away from the truck **1512**, causing the racking assembly **1504** to rotate about the pivot point **1602**. When the racking assembly **1504** is in a horizontal position, the truck **1512** is withdrawn from the cabinet **302**. The truck **1512** is removed from the cabinet **302** by rolling it out of the cabinet until the truck **1512** is in a position to be lifted from the rails of the racking assembly **1504**.

[0045] Figure 18A illustrates a load discharge device (LDA), or load-cable earthing switch, **1810**, which is an apparatus for grounding the load-side conductors when the contactor is in the open position. The LDA **1810** is illustrated schematically as a switch **214** in Figure 2. The LDA **1810** illustrated in Figure 18A is in the unearthed position, that is, the earthing bar **1806** is positioned away from the terminal lugs **1802** and the springs (only one spring **1844** is illustrated, the other is hidden by the insulating tube **1842**) are charged, or compressed. The illustrated embodiments of the LDA **1810** are low-profile devices that occupy little more space than the load-side terminals. The LDA **1810** includes a molded base **1872** that secures many of the individual components. In one embodiment, the support plate **1874** is attached to the molded base **1872**. In another embodiment, the support plate **1874** and the molded base **1872** form an integral piece.

[0046] The LDA operator **1815** has a racking connector **1812**, which engages a racking screw **1814**, and flag windows **1817** and **1819**, which indicate the earthing switch **1810** position and LDA **1810** charged status. When tripped, the earthing bar **1806** is pushed by the springs **1844** against the terminal lugs **1802**, causing the terminal lugs **1802** to be shorted and earthed through the earthing connection **1804**. For illustration purposes, three different sizes of terminal lugs **1802A**, **1802B**, and **1802C** are shown in Figure 18A. Two lugs **1802A** and **1802C** each have a small opening **1803A** and **1803C** for receiving a conductor having a low or medium current rating. The center lug **1802B** has a large opening **1803B** for receiving a large conductor with a high current carrying capacity. The lugs **1802** are swaged to the conductors as illustrated in Figure 10.

[0047] Figures 18B and 18C illustrate the position of the earthing bar **1806** with respect to the lugs **1802**. In Figure 18B, the earthing bar **1806** is in the ungrounded position and the LDA **1810** is charged and ready to earth the load-side conductors. In Figure 18C, the earthing bar **1806** is in the earthing position; that is, the earthing bar **1806** is in contact with the grounding notch **1854** (see Figure 18E) on each of the lugs **1802**. The earthing bar **1806** engages a first end of the springs **1844** and has a grounding connector **1804** for connecting the earthing bar **1806** to earth. The second end of the springs **1844** rests against the base **1872**. The springs **1844** provide the motive force for earthing by quickly forcing the earthing bar **1806** against the lugs **1802** when the LDA **1810** is tripped. In the embodiment illustrated in Figures 18A, 18B, and 18C, the earthing bar **1806** is a plate that contacts the springs **1844** and the lugs **1802**. In another embodiment, illustrated in Figure 18D, the earthing bar **1806'** is a round bar that contacts the springs **1844** and the lugs **1802**.

[0048] Figure 18D illustrates the position of the actuating mechanism and the charging mechanism on the support plate **1874** when the LDA **1810** is in the earthed position. As illustrated in Figure 18A, when the LDA **1810** is charged, the scissors-type linkage first member **1832** and second member **1828** are aligned in an almost-straight-line alignment and have a common first pivot **1860** constrained in a slot **1862** in a third member **1830**. Because the linkage members **1832** and **1828** are aligned with the pivot **1860** below the straight-line alignment position and the pivot **1860** is restrained from moving lower

vertically by a stop **1864** on the backing plate **1874**, the linkage members **1832** and **1828** are fixed in position by the springs **1844** and hold the linkage in a stable over-toggle position. The LDA **1810** is tripped by rotating the screw **1814** which rotates the plate **1816** about the hex nut pivot **1831**. The counter-clockwise rotation of plate **1816** forces the vertical member **1830** upwards pushing the pivot **1860** vertically. This rotates the member **1832** out of the almost-straight-line alignment (toggle) with the member **1828**. Once the pivot **1860** is above the straight-line alignment position, the members **1832** and **1828** no longer oppose the springs **1844**. The unrestrained springs **1844** force the rails **1822A** and **1822B** and the connecting member **1826** to travel toward the vertical member **1830**, causing members **1832** and **1828** to fold around the pivot **1860**, such as scissors do when closing.

[0049] The rails **1822A** and **1822B** and the connecting member **1826** form a sliding member made of insulating material and have a shape similar to a sideways "h". The grounding bar **1806** bridges the rails **1822A** and **1822B** and operates in concert with the rails **1822A** and **1822B**. In one embodiment, the connecting member **1826** includes two insulating bars, each one attached to a side of the rails **1822A** and **1822B**. As the rails **1822A** and **1822B** move, so does the grounding bar **1806**.

[0050] Once the pivot point **1860** is moved above the straight-line alignment, the force of the springs **1844** causes the pivot point **1860** to move at a high rate of speed along the slot **1862** in the vertical member **1830**, and, consequently, the earthing bar **1806** is forced against the lugs **1802**. The flags **1834** and **1836** are actuated by the member **1832**, indicating the charged status of the LDA **1810** through the flag windows **1817**. The lower rail **1822B** moves longitudinally and its position corresponds to that of the earthing bar **1806**. When the LDA **1810** is tripped and the load-cables are earthed, one end **1838** of the lower rail **1822B** is visible from the window **1819** in the operator **1815**.

[0051] The LDA operator **1815** includes a racking connector **1812**, which receives a racking crank (not illustrated) and engages the racking screw **1814**. The racking screw **1814** causes the member **1830** to move vertically and forces

the scissors-type linkage members **1832** and **1828** into an almost-straight-line alignment.

[0052] Figure 18E illustrates terminal lug **1802A**, which has a barrel **1852**, a lug pad **1856**, and a grounding bevel **1854**. The grounding bevel **1854** forms a notch with the molded base **1872** when the lug **1802A** is adjacent the molded base **1872**. The lug pad **1856** has a flat surface for connecting the load-side cable terminal lug (not illustrated). The lug pad **1856** has two openings **1858A** and **1858B**, through which mounting fasteners pass and secure the load-side cable terminal connection. The lug **1802A** has an opening **1803A** that passes through the barrel **1852** and receives a cable conductor. The lug **1802A** can be swaged to the conductor in a manner as illustrated in Figure 10. Those skilled in the art will recognize that other means for connecting the conductor to the lug **1802A** can be employed without departing from the spirit and scope of the present invention. The lug **1802A** has a tang **1853** that protrudes perpendicular to the barrel **1852** and is received by a slot in the lug holder **1805**. The tang **1853** secures the lug **1802A** and prevents the lug **1802A** from being displaced longitudinally when the earthing bar **1806** strikes the grounding bevel **1854**. The opening **1858C** receives a pin, fastener, or other positioning member that secures the lug **1802A** and prevents the lug **1802A** from being displaced orthogonally from the support plate **1874** when the earthing bar **1806** strikes the grounding bevel **1854**.

[0053] Figure 19 illustrates the disconnect switch **1902** and the fuses **1906**. The disconnect switch **1902** and the fuses **1906** are illustrated as the switch **204** and fuses **206** in Figure 2. The disconnect switch **1902** is secured to a support plate **322**, which is located in the mid-section of the cabinet **302** (illustrated in Figure 3). The bottom portion of the lower disconnect switch contacts **2206** (illustrated in Figures 22 and 23) are the upper fuse holders **1904**. The lower fuse holders **1908** are similar to the upper fuse holders **1904**. The lower fuse holders **1908** are electrically connected to the contactor. The fuses **1906** are conventional fuses that provide overcurrent protection. Although Figure 19 shows only a set of three fuses **1906A**, **1906B**, and **1906C**, in various embodiments, either six or nine fuses can be used, with two or three fuses **1906** in parallel, respectively. Two fuses **1906** in parallel use a two-fuse holder **2010** as illustrated in Figure 20A. Three fuses **1906** in parallel use a

three-fuse holder assembly **2022** as illustrated in Figure 20B. This configuration of fuses **1906** permits removal and replacement of the fuses **1906** without removing, or withdrawing, the contactor or disconnect switch **1902**. Additionally, the operator of the disconnect switch **1902** is interlocked with the contactor door **304** such that the door **304** cannot be opened and the fuses **1906** or other high-voltage components cannot be accessed unless the disconnect switch **1902** is in the open position.

[0054] Figure 20A illustrates a two-fuse holder **2010**, such as the lower fuse holder **1908**, which includes a pair of fuse clips **2006A** and **2006B** and an outer shroud **2004**. Figure 20B illustrates a top view of the fuse holder **2010** illustrated in Figure 20A and a single fuse holder **2020**, which is secured to the fuse holder **2010**. The shrouds **2004**, **2014** of the lower fuse holder **1908** include mounting holes **2022** for securing the shrouds **2004**, **2014** to a support plate **1912**. The shrouds **2004**, **2014** of the upper fuse holder **1904** are cast with the lower disconnect switch contacts **2206** (illustrated in Figures 22 and 23) and do not have mounting holes **2022**.

[0055] The fuse clips **2006** are conventional fuse clips that mate to the fuses **1906**. Referring to Figure 19, each fuse **1906** is installed by first seating the upper end of the fuse **1906** in the fuse clip **2006** in the upper fuse holder **1904**, and then pushing the fuse **1906** into the fuse clip **2006** in the lower fuse holder **1908**. Those skilled in the art will recognize that the fuse clips can be any type that mates with the type of fuse used in the controller **102** without departing from the spirit and scope of the present invention.

[0056] The shroud **2004** is formed of a single casting of aluminum, plated copper, or other conducting material and has rounded surfaces, which minimizes the electrical stress and reduces corona. The shroud **2004** surrounds the sides of the fuse clips **2006** and, for the lower fuse holder **1908**, has a side opening **2008** for the fuse **1906** to be inserted into the fuse clip **2006**. The upper fuse holder **1904** does not require the side opening **2008**. In one embodiment, illustrated in Figures 22 and 23, the upper fuse holder **1904** includes rounded slots through which the engagement of the fuse **1906** can be inspected and to provide access to the fuse clip **2006**.

[0057] Figure 20B illustrates a three-fuse holder assembly **2022** including a two-fuse holder **2010** attached to a single fuse holder **2020** by a fastener **2032.** Those skilled in the art will recognize that the fastener **2032** can be a bolt **2032** and nut **2034**, a rivet, or other type of fastener without departing from the spirit and scope of the present invention.

[0058] Figure 21 illustrates a housing **2104** of the disconnect switch **1902** and a switch illuminator **2150**. The housing **2104** includes a window **2108**, through which the internals of the housing **2104** can be viewed. The disconnect switch **1902** includes an operator connector **2102**, into which an operator handle fits. Rotating the operator handle, and the operator connector **2102**, operates the disconnect switch **1902**, which is shown schematically in Figure 2 as the disconnect switch **204**. The line-side connection is made directly to the bus connection tabs **2302** protruding above the housing **2104**. This direct connection eliminate risers or other extraneous electrical connections to the disconnect switch **1902** and serves to reduce potential heat generating connections. The line-side bus is shown as the bus **202** on Figure 2.

[0059] Figure 22 illustrates the internals of the disconnect switch **1902** in the closed position, including the upper switch contacts **2204**, the switch blades **2204**, the operator shaft **2212**, and the lower switch contacts **2206**. Figure 22 shows an embodiment of a lower switch contact **2206A** having a single fuse holder **2020** (also shown on Figure 20B). Figure 22 also shows an embodiment of the lower switch contact **2206B** and **2206C** having a two-fuse holder **2010** (also shown on Figures 20A and 20B). Figure 22 shows the two embodiments for illustrative purposes because, typically, only one embodiment would be used in a controller **102** at a time. Figure 23 illustrates a cross-section view of the internals of the disconnect switch **1902** illustrated in Figure 22, with the addition of the grounding stabs **2324** protruding from the grounding bar **2322**, which grounds the load-side of the disconnect switch **1902** when the switch **1902** is in the open position. The grounding stabs **2324** and the grounding bar **2322** are not illustrated in Figure 22. The illustrated embodiment of the disconnect switch **1902** has cast parts to minimize the number of components and reduce the number of heat generating connections.

[0060] Each upper switch contact **2202** includes a bus connection **2302**, a mounting pad **2306**, and an upper contact **2304**. The upper switch contact **2202** is formed from a conductive material. The bus connection **2302** includes flat connection surfaces to which either bus bar or cable connectors can be bolted. The mounting pad **2306** has openings used to attach the upper switch contact **2202** to the housing **2104**. Those skilled in the art will recognize that any of various types of fasteners can be used to secure the upper switch contact **2202** to the housing **2104** without departing from the spirit and scope of the present invention.

[0061] Each lower switch contact **2206** includes the lower contact **2314**, a mounting pad **2222**, and an upper fuse holder **2206**. The lower switch contact **2206** is formed from a conductive material. The mounting pad **2222** has openings **2224** used to attach the lower switch contact **2206** to the housing **2104**. Those skilled in the art will recognize that any of various types of fasteners can be used to secure the lower switch contact **2206** to the housing **2104** without departing from the spirit and scope of the present invention.

[0062] Each switch blade **2204** includes two flat bars **2204'** and **2204"** that sandwich the upper contact **2304** and a lower contact **2314**. The switch blades **2204** are formed from a conductive material. The operator shaft **2212** is connected to the operator connector **2102** outside the housing **2104** and to the switch blade holders **2214** inside the housing **2104**. Each switch blade holder **2214** contains a pair of parallel switch blades **2204'** and **2204"**. Internally, the switch blade holders **2214** include springs that force the switch blades **2204** against the upper contact **2304** and the lower contact **2314** such that electrical continuity is established between the upper switch contact **2202** and the lower switch contact **2206** when the disconnect switch **1902** is positioned in the closed position illustrated in Figure 22.

[0063] Figure 23 illustrates a section view of the switch internals, including the grounding stab **2324** and the grounding bar **2322**. As the operator shaft **2212** rotates counterclockwise, the switch blade holders **2214** cause the switch blades **2204** to rotate about the operator shaft **2212** towards the open position. With the disconnect switch **1902** in the open position, the switch blades **2204** have been rotated away from the upper contact **2304** and

the electrical continuity between the upper switch contact **2202** and the lower switch contact **2206** is broken. The grounding stab **2324** is the same width as the upper contact **2304** and, when the switch **1902** is in the open position, the switch blades **2204** make electrical contact with the grounding stabs **2324**, grounding the load-side of the disconnect switch **1902**.

[0064] Figure 24 illustrates the switch illuminator **2150** for illuminating the internals of the disconnect switch **1902**. Figure 25 illustrates a simple schematic diagram for the switch illuminator **2150**. The switch illuminator **2150** includes a push-button switch **SW1**, a current limiting resistor **R1**, a power supply **2502**, and an LED **L1**. The push-button switch **SW1** has an actuator **2152** that extends from the illuminator case **2156**. Extending from the opposite side of the illuminator case **2156** is a light pipe **2154**, which can be the lens that is integral with the LED **L1** or a separate optical pipe that collects the light emitted from LED **L1** and pipes it to the disconnect switch **1902**. The light pipe **2154** mates with an opening **2106** in the disconnect switch housing **2104**. The power supply **2502** can be a portable power supply, such as a battery, or a permanent power supply, which can be obtained from the instrument compartment **1310** or other source in the controller **102**.

[0065] The switch illuminator **2150** is a self-contained illuminator that eliminates the need for an operator to have a flashlight to view, through the window **2108** in the housing **2104**, the interior of the disconnect switch **1902** and determine whether the disconnect switch **1902** is open or closed. Pushing on the actuator **2152** operates the switch **SW1** and causes the light pipe **2154** to illuminate the interior of the disconnect switch **1902**.

[0066] Figure 26 illustrates a schematic of a low power current transformer **2610**. Prior art current transformers are sized for the current flow to be detected. Prior art current transformers have a ratio based on the current to be detected, for example, 25/5 and 800/5. The low power current transformer **2610** detects a wide current range and is suitable for measuring any current in the range from 0 amperes to 800 amperes, or more. The low power current transformer **2610** is illustrated as the current transformers **216A**, **216B**, **216C**, and **218** on Figure 2.

[0067] The low power current transformer **2610** includes a winding **CT1**, through which the current carrying conductors **2602** pass, and a resistor **R2**. In one embodiment, the low power current transformer **2610** is mounted on a chassis that supports the draw-out stabs that mate with the contactor. The conductors **2602** are electrically connected to the draw-out stabs and, in one embodiment, the conductors **2602** include all three phases of the load. In another embodiment, the conductor **2602** is a single phase of the load. Across the secondary winding **CT1** is a resistor **R1**, which is connected to the protective device **2606** through a grounded shielded cable **2604**. In one embodiment, the resistor **R1** is molded in a protective casing that also protects the winding **CT1**. The protective device **2606** is responsive to a voltage signal that represents the current flow through the primary of **CT1**. In another embodiment, the shielded cable **2604** connects to a meter or other transducer, which provides current indication. In one embodiment, the shielded cable **2604** is grounded to one conductor. In another embodiment, the shielded cable **2604** has an isolated ground.

[0068] In one embodiment, the secondary winding **CT1** is a conventional 2500/1 current transformer, the resistor **R2** has a value of 0.5625 ohms, and the output of the low power current transformer **2610** is 22.5 millivolts per 100 amps through the primary of **CT1**. In another embodiment, the resistor **R2** has a resistance of 0.2475 ohms.

[0069] Figure 27 illustrates a block diagram of an internal temperature monitoring system **2714**. The internal temperature monitoring system **2714** permits direct temperature monitoring of specific components and eliminates the need for remote and less precise temperature monitoring systems. The internal temperature monitoring system **2714** uses a ruby crystal **2712** in direct contact with the component to be monitored. Components that can be monitored include the bus connections to the disconnect switch **1902**, the draw-out stabs, the fuse holders **1904** and **1908**, the load-side terminations made at the LDA **1810**, and any other component that is subject to temperature variations.

[0070] The ruby crystal **2712** is excited by a source **S1** signal generated by a source **2704** and transmitted over a source fiber optic cable **2722**. The

fluorescence signal **S2** is captured by a detector fiber optic cable **2724**, passed through a filter **2708**, and sensed by a detector **2706**. The fiber optic cables **2722** and **2724** are non-conductive and have a high dielectric strength.

[0071] Figure 28 illustrates the waveforms for the source **S1** and fluorescence **S2** signals. The source signal **S1** is a square wave pulsed signal that excites the ruby crystal **2712**. The fluorescence signal **S2** produced by the crystal **2712** varies according to the temperature of the crystal **2712**.

[0072] The processor **2702** monitors the source **2704** and receives the output of the detector **2706** to determine the temperature of the crystal **2712**. In one embodiment, the processor **2702** has a bistable output that changes state when the temperature of the crystal **2712** reaches a set value. In another embodiment, the processor **2702** has an output corresponding to the temperature of the crystal **2712**.

[0073] From the foregoing description, it will be recognized by those skilled in the art that a medium voltage motor controller has been provided.

[0074] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicants to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus, and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the spirit or scope of applicants' general inventive concept.